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DESIGN FOR PRODUCIBILITY

A Design Producibility Algorithm

BALLISTIC SYSTEMS DIVISION
Directorate of Manufacturing

March 1990

INTRODUCTION

It doesn't take 20/20 vision to see that U.S. military weapons programs are in big trouble. Developing the increasingly sophisticated weapons needed to meet the challenge of high-tech warfare is taking too long, and the price giving "sticker shock" to the American public. To meet the challenge to reduce cost and development time for new weapon systems, the Commander of the Air Force Systems Command has identified the need to field more reliable, supportable and producible hardware to meet our users' needs, but translating that objective into *action*, especially when it comes to producibility, is easier said than done.

Design for Producibility goes under a number of different names today; sometimes it is called "Design for Manufacturing and Assembly," "Design for Simplicity," "Design for Quality," "Design for Competitiveness," or "Six-Sigma Design." All these concepts focus on improving producibility, but before we get involved in *improving* the producibility of our designs, we should first agree on how to *do* it. How do you "do producibility"? When we asked that question at meetings with contractors around the U.S., we found only a few who were able to cogently answer. Explanations ran the gamut from extreme analytical methods that were unusable in a real-world design environment to oversimplified "producibility checklists" that were sometimes used as a substitute for rational thought.

To meet the need, the Ballistic Systems Division Manufacturing Directorate has developed an algorithm that: (1) *Outlines a comprehensive approach to producibility* from concept exploration to production; (2) *integrates both manufacturing planning and design engineering* to insure a systematic and concurrent effort to achieve design producibility; (3) *provides a logical flow* that may be used to develop producibility procedures for specific systems; and (4) *gives us a "template" to evaluate producibility effectiveness* on a program.

The Design Producibility Algorithm outlined in this paper is an information decision flow that begins with the conceptual phase and ends with the production decision. It provides a structured thought process which includes the analysis of capability and capacity to manufacture the required hardware given various levels of design certainty. The upper level flow diagram, along with the detailed flow diagrams and explanations presented herein, provide the algorithm necessary to aid in creating and executing a successful design producibility program.

We are publishing this pamphlet to train our own acquisition managers and to communicate our producibility requirements to the BSD Associate Contractor community. We welcome your input, either in the form of questions or suggested improvements.

ACKNOWLEDGEMENTS

We want to express our thanks to the following Ballistic Systems Division and TRW personnel, whose direct contributions and critical evaluations made this project possible:

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Jim Walraven, Manufacturing Section Chief

Mike McGrath, Staff Producibility Engineer

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Richard E. De Sanze, Director of Manufacturing

Art Temmesfeld, Editor and Producibility Engineer

And to the man, without whose vision and constant pressure this project would have been shelved long ago...

Colonel William W. "Walt" Bryan, USAF (Ret.)
Former BSD Deputy for Product Assurance

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DESIGN FOR PRODUCIBILITY

1.0 BACKGROUND

1.1 DEFINITION AND SCOPE

What is producibility? Looking at the *product*, MIL-HDBK-727 defines producibility as "a measure of the relative ease of producing a product"; however, this definition tells us little about *how to do* design producibility engineering. Our purpose is to focus on the *process*, or to explain how to "do producibility." For the purposes of this paper, then, we will define producibility as "**an *iterative* process of intense and continuous interaction between design and manufacturing to arrive at a product that is producible.**"

1.2 OBJECTIVES

The objectives of an effective producibility program should be to: (1) make every design decision in full light of the manufacturing impact, (2) ensure that capability and capacity development and implementation support program schedules, (3) ensure that manufacturing methods and processes are stable by CDR, (4) ensure minimal (ideally zero) post CDR design changes, (5) attain one hundred percent yield, and (6) maintain the lowest unit production cost possible.

2.0 RESPONSIBILITIES

2.1 PROGRAM MANAGEMENT

The Program Manager creates and funds a producibility program during engineering development and continues it into initial production. He emphasizes producibility along with reliability and maintainability in all source selections for new and modified designs. He establishes measurable program producibility objectives, and he ensures that accepted producibility practices are followed throughout product development and production.

To demonstrate that all major development problems impacting production have been resolved, some limited expenditure may be required for production prototypes during development. Funds may have to be allocated for development of new production methods, procedures, and processes; manufacturing engineering; production-run tooling, and/or essential production tests and demonstrations.

2.2 DESIGN ENGINEERING

Design Engineering personnel take the lead to integrate producibility with the design to make sure that it is a primary consideration and that producibility best practices are followed in all design activities. They concentrate the efforts of the design team to evaluate all trade studies for manufacturing impact, and they identify all design options available to ensure that solutions satisfy producibility criteria. They review engineering change proposals for producibility considerations and they make sure that producibility is a focus of each design review.

2.3 MANUFACTURING ENGINEERING

Manufacturing engineering personnel take an active role during program planning, design, development, and production to ensure that designs can be effectively and economically manufactured at production rates. They determine lead times, schedules, and production reporting requirements, and they provide an active manufacturing interface with other functional specialists. They detect and resolve production risks to minimize problems of transition from development to production. To do this, they continually monitor industrial processes, techniques, and controls to determine whether the program plan and milestones can

be achieved, and they anticipate potential problems, and take action to prevent or minimize adverse impact.

Manufacturing personnel also assess production feasibility, provide necessary visibility of manufacturing costs and potential schedule impacts, and plan for quantity production with the most economical and efficient use of manpower, materials, machines, facilities and methods. To carry out these tasks, they actively participate in System Requirements Reviews (SRRs), Design Reviews (SDRs), Preliminary Design Reviews (PDRs), Critical Design Reviews (CDRs), and other program reviews during design, development, and production phases of the program.

3.0 PRODUCIBILITY TOOLS

Producibility tools, though important, are useless without a cultural change to the systems and design engineering process. You need to change the attitude from, "We are here just to make a product that *works*," to the attitude, "We are here to design a product that can be *made*" To do this, you need management commitment and continuous dialogue between functional engineering groups - what is known as *concurrent engineering*. The following tools are minimal to a good producibility program. [Three additional tools are identified in Section 4.1.]

3.1 State-of-the-art reviews are reviews that define the latest technologies available. These reviews take advantage of trade magazines, trade shows, telephone surveys, industry and government agency data bases, etc. to ensure that the latest state-of-the-art equipment, tooling, processes, materials, etc. are known and considered for production.

3.2 A cost analysis is necessary to develop a baseline to measure against. Analyses are normally best accomplished by breaking hardware into logical subassemblies, analyzing the labor, materials, overhead, etc. required to manufacture the hardware, and combining them to estimate the total cost of the subassembly. To do this, historical costs for similar hardware, engineering estimates, and vendor quotes can be used. After a cost estimate is established, cost avoidance can be achieved by investigating alternatives such as increased automation, reduction in part quantity, process/work simplification, efficient material usage, efficient methodology and relaxation of tolerances.

3.3 Pareto analysis is used to select high cost items so efforts can be concentrated in the areas where the largest return on investment can be realized. The Pareto Principal says that 20% of the effort accounts for 80% of the cost, so concentrating on the high cost items first will allow a contractor to impact the program with minimum effort.

3.4 Critical path method predicts the time it takes to complete a task, subassembly, inspection, etc., and creates a flow of operations. The longest path is known as the "critical path". The engineer studies long cycle candidates to reduce the time to complete the task. When this is done, the critical path is altered and the next longest cycle is selected as a candidate for study, and so on, until the critical path is shortened enough to ensure overall schedule adherence.

3.5 Cost schedule optimization analyses optimize the design in consonance with performance requirements, test results, schedules, effectiveness, and design to cost/life cycle cost. Criteria for selecting cost schedule optimization study candidates include, but are not limited to, critical hardware, Pareto analysis results, and critical path method results. The object is to select the process, test, material, design and support that will best satisfy the requirements within schedule and at the lowest cost possible. Backup data and assumptions to support the selection are also made part of the study.

4.0 SCHEDULES/PHASES

4.1 PRIOR TO THE SYSTEM REQUIREMENTS REVIEW

Prior to the System Requirements Review, the contractor should have capability studies, design standards or guidelines, preferred manufacturing practices, a design team structure with assigned responsibilities for functional engineering specialists, and a defined process for make-or-buy decisions.

4.1.1 Capability Studies. Capability studies will be unique to a given contractor's operation, and will reflect his total manufacturing potential. Capabilities that should be defined include machine capabilities, tooling capabilities, personnel capabilities, and facilities capabilities. The studies should include, but not be restricted to: quantity and type of equipment, product dimension and weight limitations, tolerance capability, facility, tooling and personnel utilization, skill requirements, personnel by shift, unique characteristics (advantages, limitations, requirements), and certifications of production and support personnel. The studies should use historical production data whenever possible. On new equipment or equipment to be developed, estimates or manufacturer's specifications can be used.

4.1.2 Design Standards/Guidelines. Design standards/guidelines are manufacturing constraints for use by the design team. They should be developed so that when followed, producibility problems will be avoided. They are not intended to exclude creativity and implementation of new technology, but to identify areas of risk to be addressed. Both Manufacturing and Design Engineering should be active participants in the generation, use, and modification of the standards. They will inform designers of available manufacturing capabilities and/or restrictions. The standards should be updated when manufacturing capabilities change.

4.1.3 Preferred Manufacturing Practices. Preferred Manufacturing Practices is a handbook of processes, materials, methods, etc. with information that: Provides order of preferred methods, taking sensitivities such as volume, schedule, cost, and availability into account; identifies processes, methods or material to be eliminated or avoided; suggests recommended processes, methods and/or materials and priorities; gives helpful hints to facilitate maintainability, testability, inspectability, etc.; and reflects equipment, tooling, personnel, and facilities capabilities. These practices should be updated whenever methods, processes, and/or available materials change. MIL-Handbook 727 can also be used as a guide and thought provoker throughout development of the "Preferred Manufacturing Practices".

4.1.4 Design Team Structure/Responsibilities. Design team structure and responsibilities should be developed to best suit the individual contractor's organization and corporate philosophy, but should always include design engineering, manufacturing engineering, and quality engineering as a minimum. A suggested approach is to institute "concurrent engineering" with all involved functional disciplines, and even selected suppliers, beginning with the concept exploration stage.

4.1.5 Make-or-Buy Decision Process. The contractor should have a documented method to determine the producibility advantages to make or buy an item and a documented method to select sources for those hardware items that are to be purchased. The determination and selection processes should be developed with producibility, quality, and reliability in mind.

4.2 AT THE SYSTEM REQUIREMENTS REVIEW (SRR)

The SRR is conducted after accomplishing the functional analysis and preliminary requirements allocation. It may be conducted at any time, but it will normally be done after concept exploration and during the demonstration/validation (pre-FSD) phase. Its purpose is to determine the initial direction and progress of the contractor's system engineering management

effort. MIL-STD-1521B requires the following manufacturing and producibility issues to be addressed at the SRR:

1. Producibility analysis plans
2. Requirements tradeoffs vs manufacturing methods and processes
3. Unit production cost/design-to-cost objectives
4. Critical producibility and manufacturing considerations
5. Manufacturing risk identification and preliminary risk ranking
6. Life cycle cost analysis
7. Manufacturing methods and process constraints
8. Producibility and manufacturing considerations that could impact the program decision, e.g., critical components, materials, tooling and test equipment development, production test methods, long lead items, and facilities/personnel/skill requirements

4.3 THE FLOW FROM SYSTEM REQUIREMENTS REVIEW TO SYSTEM DESIGN REVIEW

The following flow diagrams represent the decision process leading to a feasibility decision at System Design Review (SDR). They are part of the overall Design Producibility Algorithm. When studying these charts, you should also refer to the top level flow chart on the last page.

Block 1.0 "Initial or Additional Requirements" is the start of the flow. The process begins when the functional requirements are established Any time requirements are added, deleted, or changed, we must come back to this point, if for no other reason than as a "sanity check," to make sure no manufacturing impacts have been overlooked in the design process.

Block 1.1 "Change system requirements or allocations" requires the contractor to decide whether he needs to change requirements or allocations for various reasons and then to make those changes (see detail page 6).

Block 2.0 "Has identical hardware been manufactured before?" tells us to look at past history to determine whether the identical hardware in the system has been manufactured before (see detail page 7). If it has, we need to ask whether there were lessons learned from previous production experience (block 3.0). If the hardware has not been manufactured before, requirements need to be defined for fabrication and assembly.

Block 2.1 "Define requirements for fabrication and hardware assembly" makes us outline all the necessary steps to manufacture the hardware to the present concept baseline. This includes processes, facilities, materials, equipment, tooling, components, parts and personnel. To develop this information, we use employee knowledge, past engineering data, surveys of contractors, government agencies and trade shows. In this up-front review of requirements we must assure that manufacturing is considered in all systems requirements trade studies (see detail page 8).

Block 3.0 "Design or Manufacturing changes desired due to lessons learned?" asks both the contractor and the customer to do a systematic search of their records and experience to see if they can take advantage of lessons learned from mistakes made or problems that surfaced when the hardware was previously made. Producibility checklists from MIL-HDBK-727 may also be used as thought provokers at this point in the process (see detail page 9). If there are lessons to be applied, these may affect requirements for fab and assembly (Block 2.1) .

Block 4.0 "Necessary production capabilities and capacities planned or programmed?" If all the system and manufacturing requirements are validated and a decision is made to proceed with the program (Milestone I), Block 4.0 tells us to look at the required capabilities and capacities for new production against those existing at the contractor's facility (see detail page 10). If his capabilities and capacities are sufficient, we can determine whether the

program is affordable (Block 5.0). If they are not, we must ask several other questions (Blocks 4.1 through 4.3).

Block 4.1 "Is capability and capacity development possible?" forces us to ask if the required capability can be obtained, or if it can be obtained at the necessary capacity to satisfy program schedules. To answer this question, the contractor first has to find out whether he had the capability in the past. If he did, he has to define what he needs to reacquire the capability. If he did not have a past capability, he must define requirements to develop the new capability (see detail page 11). If the contractor can obtain a capability or capacity to meet current system requirements, he will establish cost and schedule estimates to do it (Block 4.2). If he can't reacquire that capability or establish a new capability, he must inform his customer, who will then decide whether to change his system requirements or get a new contractor (Block 1.1).

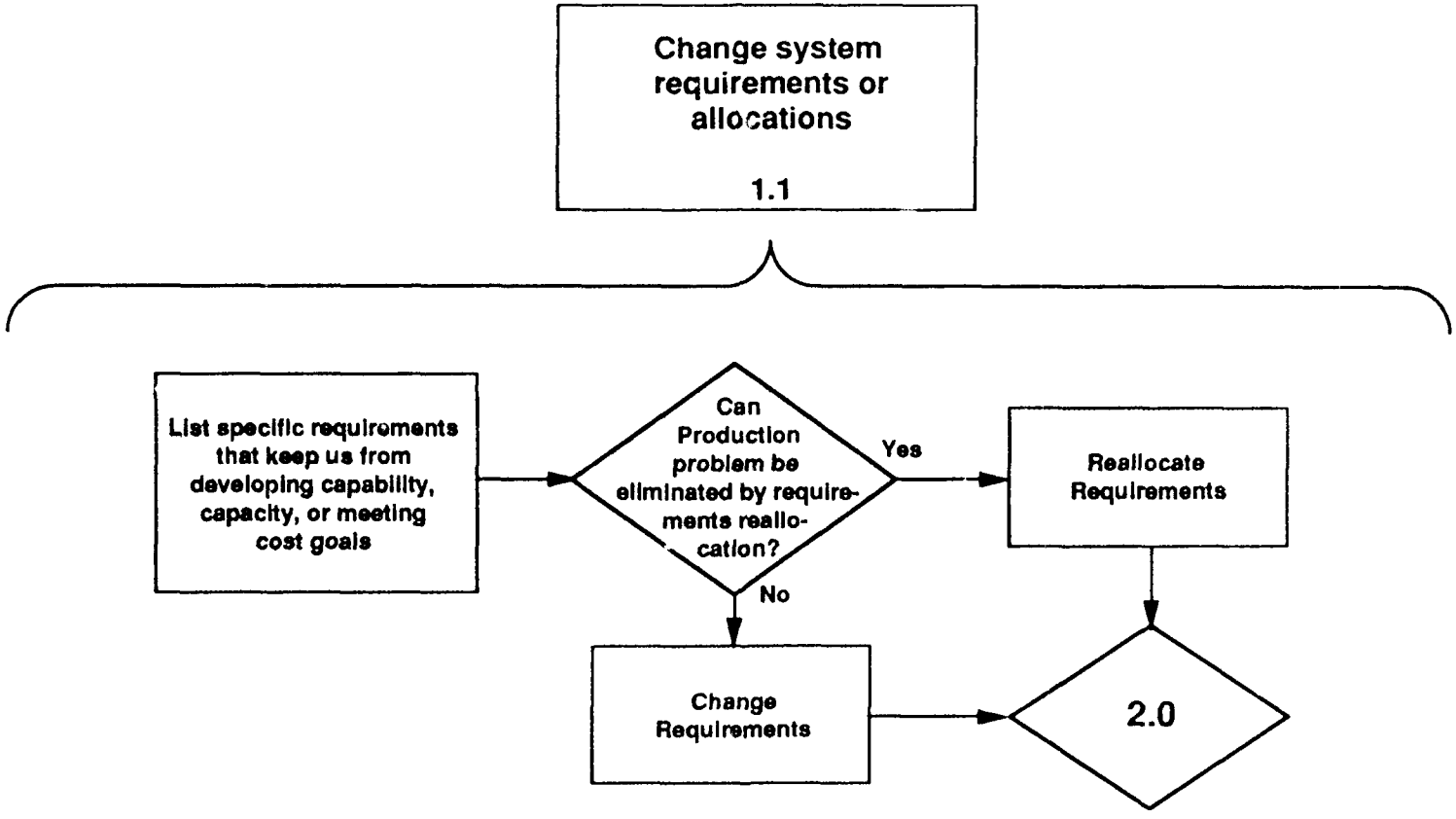
Block 4.2 "Establish estimate of cost and schedule to obtain capability and capacity and perform overall risk assessment" requires the contractor and the customer to perform cost and schedule reviews based on similar capability or capacity, or based on engineering estimates if capability and capacity data do not exist. They will develop a cost and schedule model, assess the risk associated with developing the capability and capacity, and make recommendations for mitigating that risk (e.g., use of special incentives such as MANTECH or IMIP) (see detail page 12).

Block 4.3 "Plan or program capability/capacity knowing cost and schedule risk?" is where we determine if we want to go ahead and develop the new capability or capacity knowing the cost, how long it will take, and how much technical risk is involved (see detail page 13). The contractor needs to ask if the projected cost as schedule will meet program needs. If not, will work-arounds still allow him to meet schedule? If the answer is no, he must inform his customer, who will again decide whether he wants to change system requirements (Block 1.1). If the answer is yes, he must determine if the program is affordable (Block 5.0).

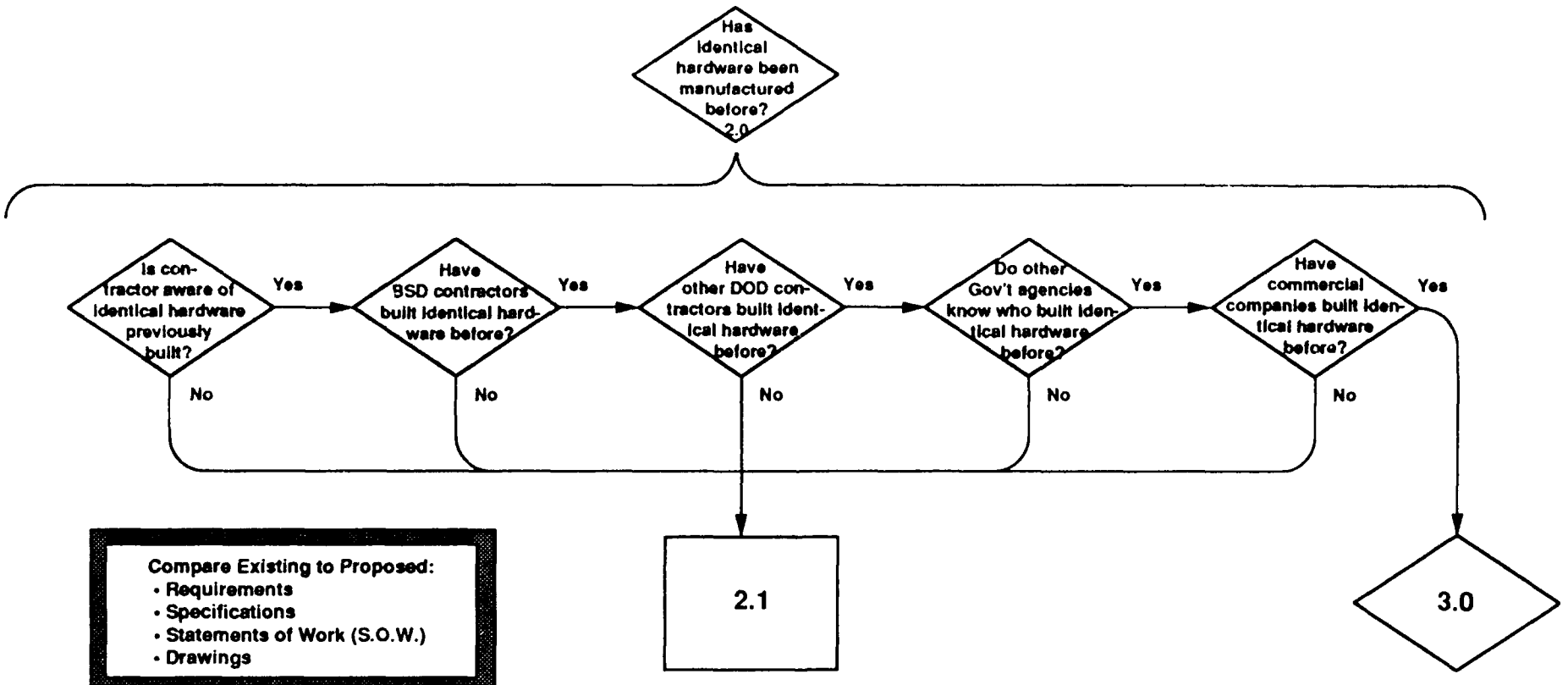
Block 5.0 "Program affordable considering recurring and nonrecurring costs?" requires the contractor and the customer to examine estimated costs for facilities, tooling, personnel, etc. and determine if the planned program has a reasonable cost compared to current budget limits (see detail page 14). They will perform a cost review based on similar programs or engineering estimates. If the customer determines that performance and manufacturing quality requirements can be met within schedule and funding limits, and that there are no alternatives at this point that are more likely to achieve program goals, they will determine the concept to be manufacturable (Block 6.0). If the concept is not manufacturable, systems requirements or allocations must be changed (Block 1.1).

Block 6.0 "System concept manufacturable" comes at Milestone II, before we enter FSD. It is a checkpoint that says both the contractor and the customer have determined that the baseline or modified concept provides the best value for the customer's dollar (see detail page 15). Because this is an iterative process, *Block 6.0 is a gate that must be passed through each time system requirements or allocations are changed.* If the changes are minor, it may be necessary only to perform minor updates to studies previously accomplished; if they are major, it may be necessary to scrap the previous studies and begin all over again.

Manufacturing Feasibility: 1.1



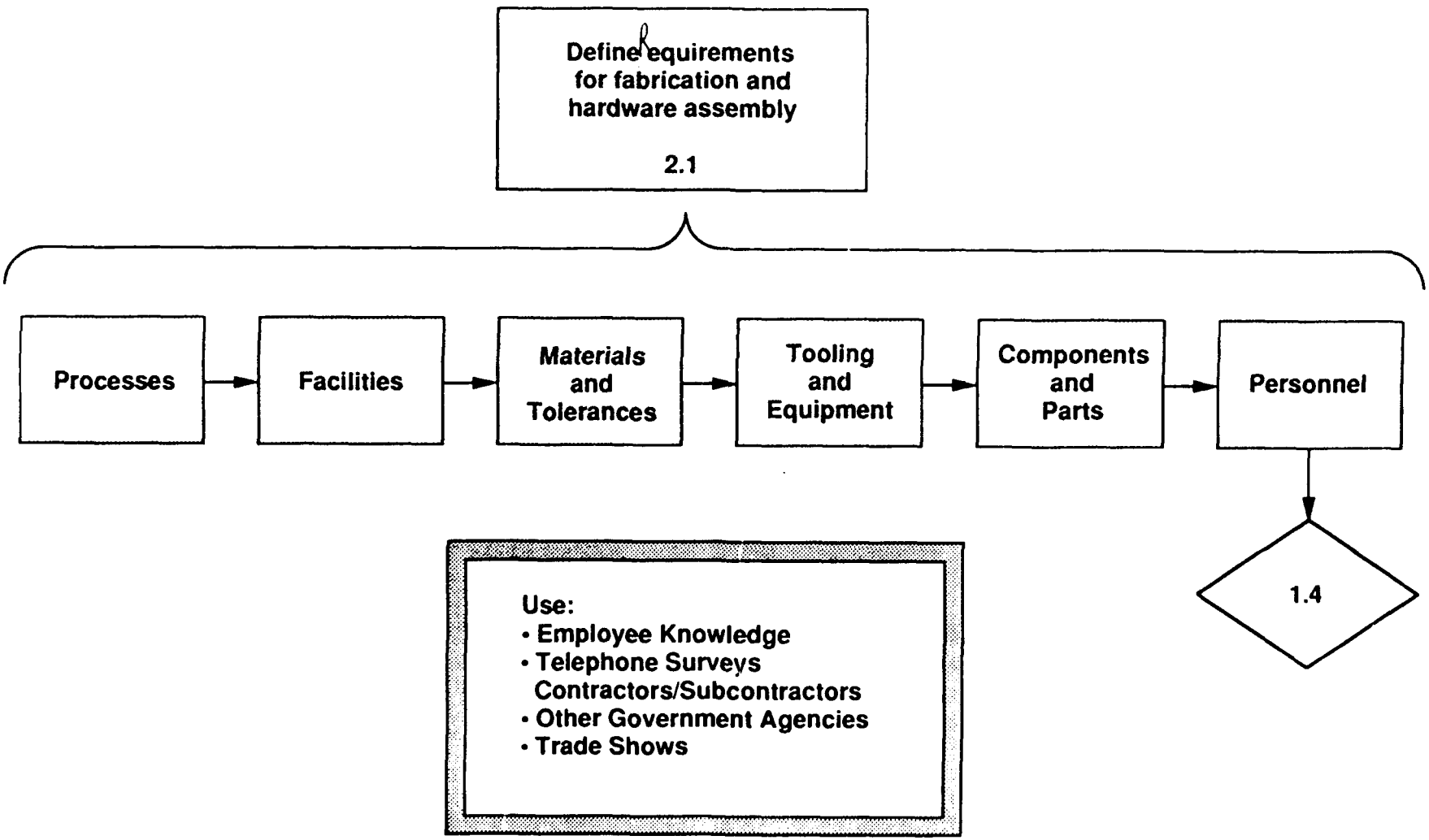
Manufacturing Feasibility: 2.0



Compare Existing to Proposed:
- Requirements
- Specifications
- Statements of Work (S.O.W.)
- Drawings

Sources of Information:
- Contractor/Subcontractor Knowledge
- Trade Magazines
- Trade Shows
- Other Divisions
- Telephone Surveys
- Employee Knowledge

Manufacturing Feasibility: 2.1



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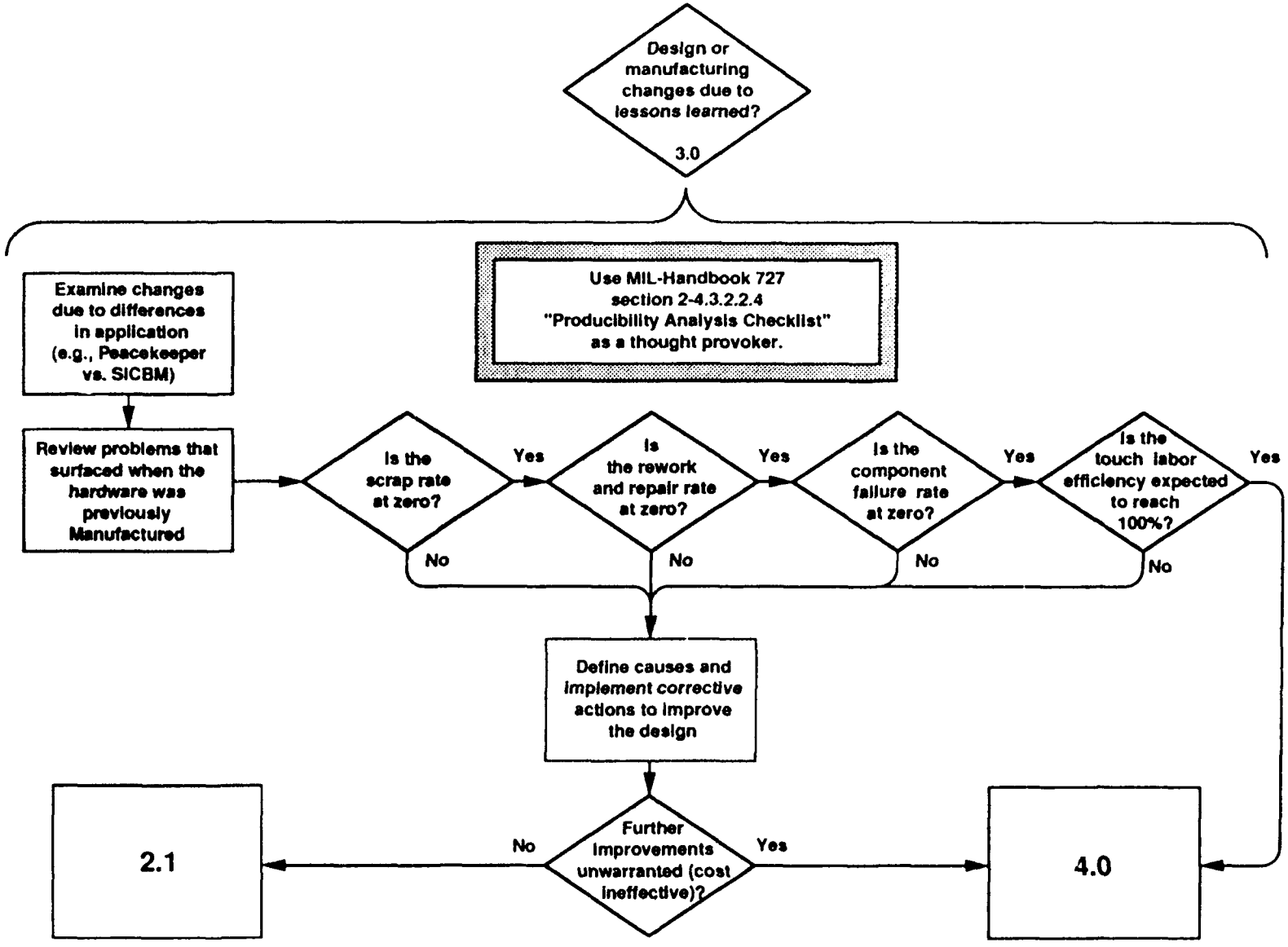
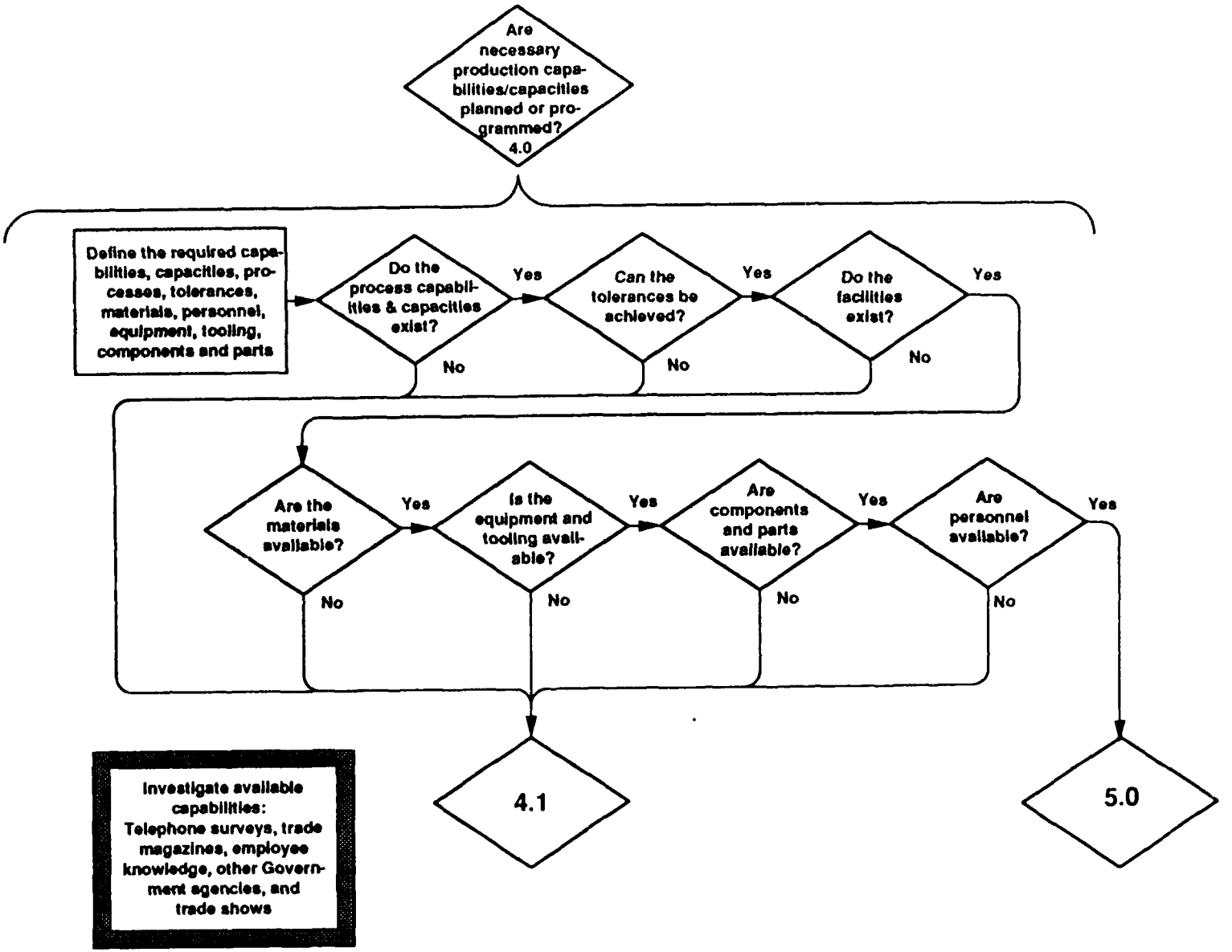


Manufacturing Feasibility: 4.0



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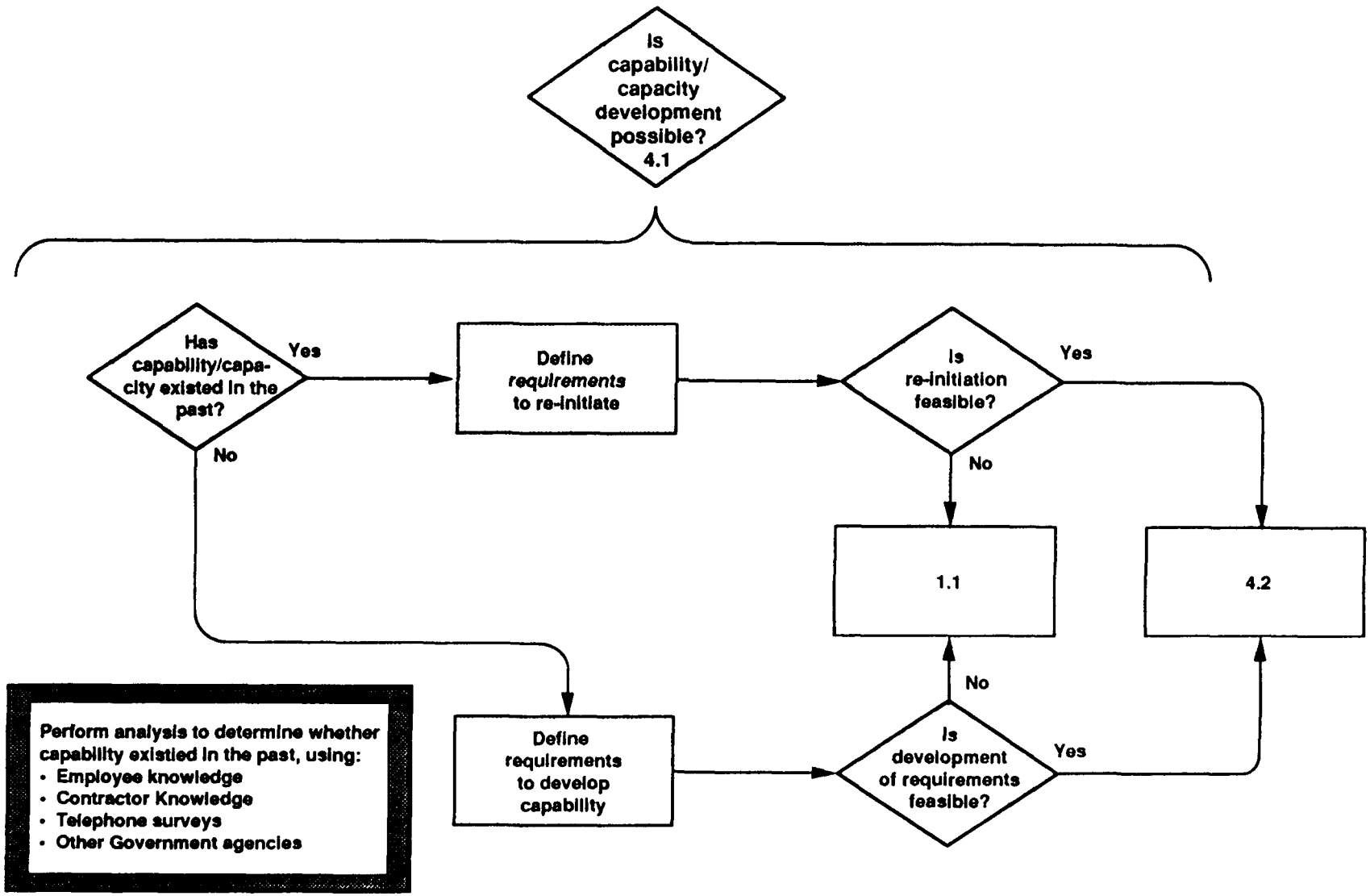

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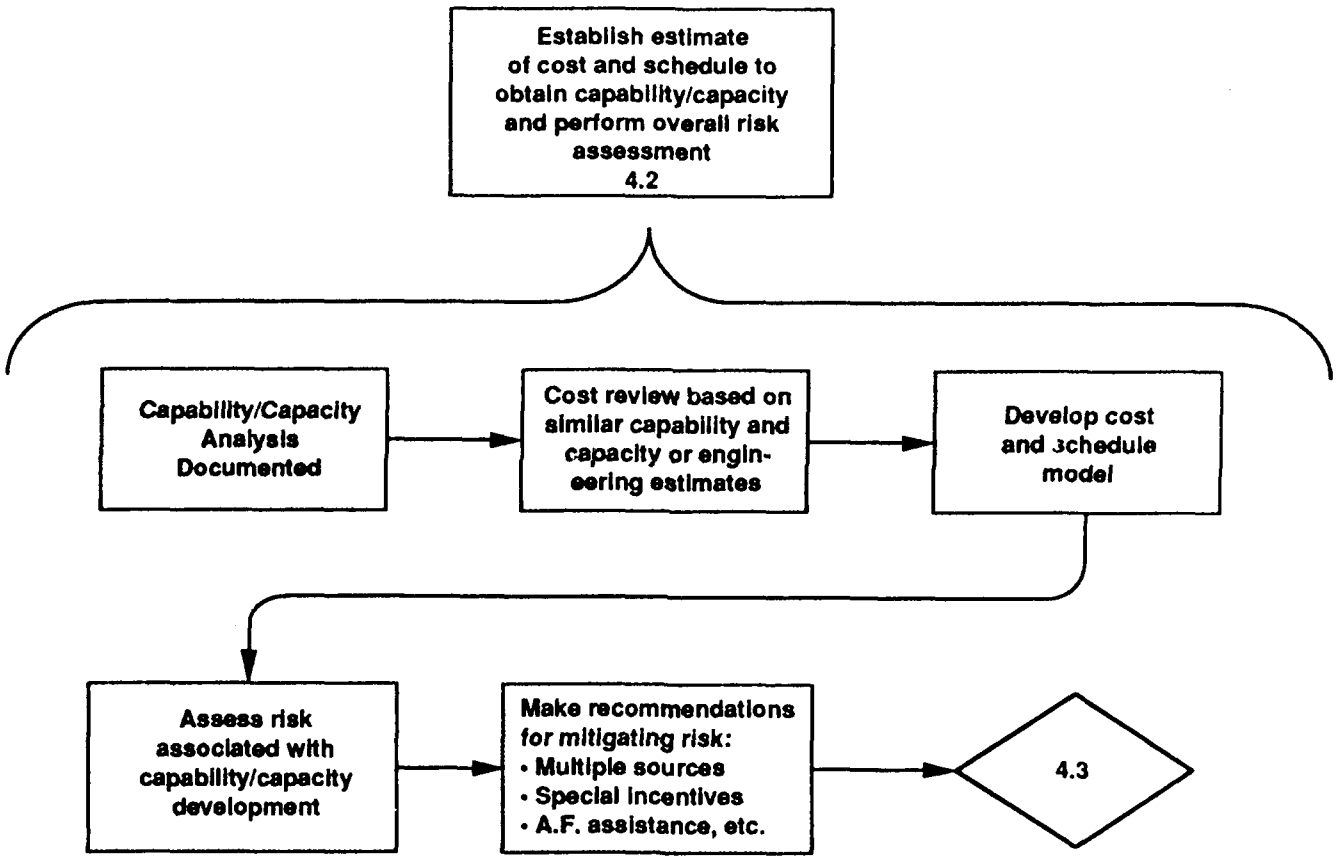

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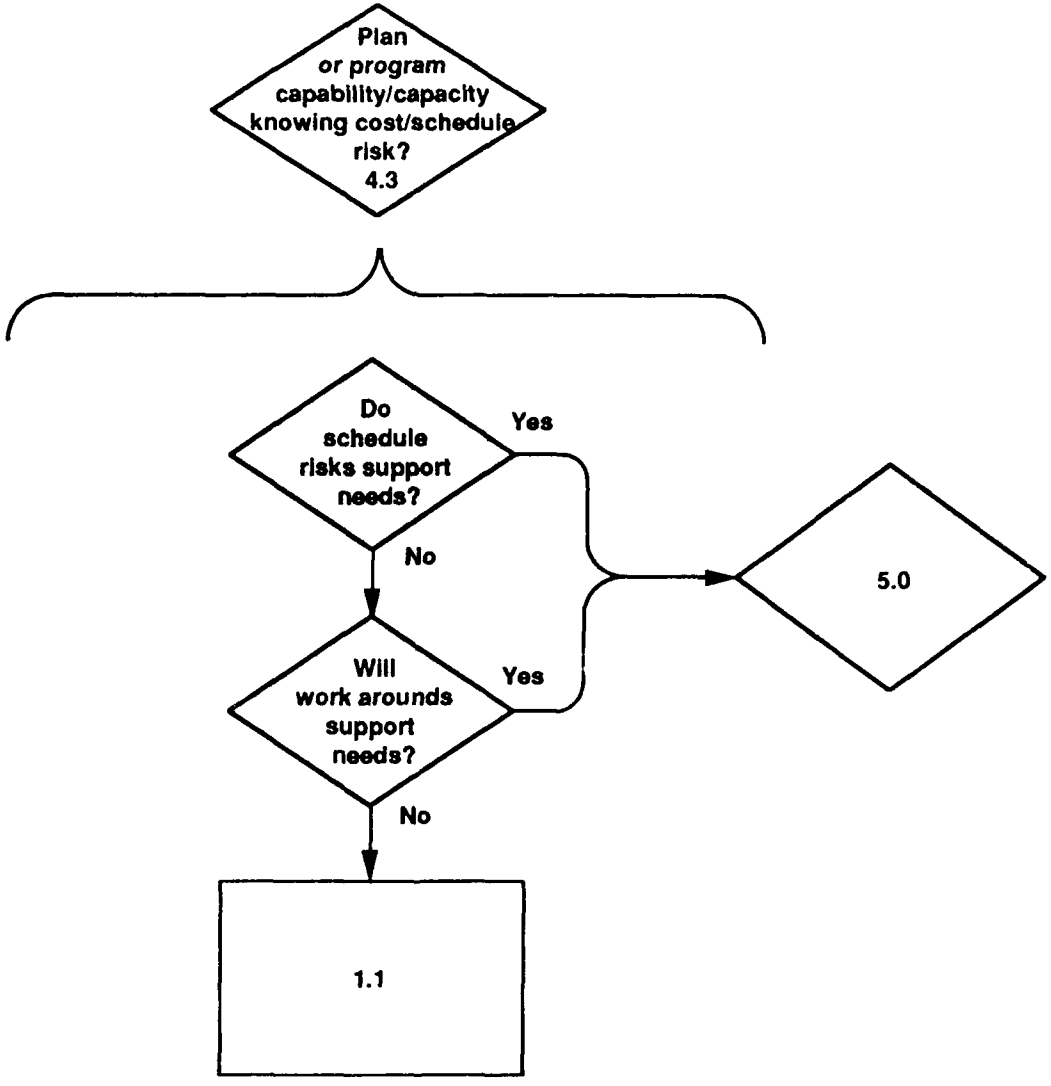

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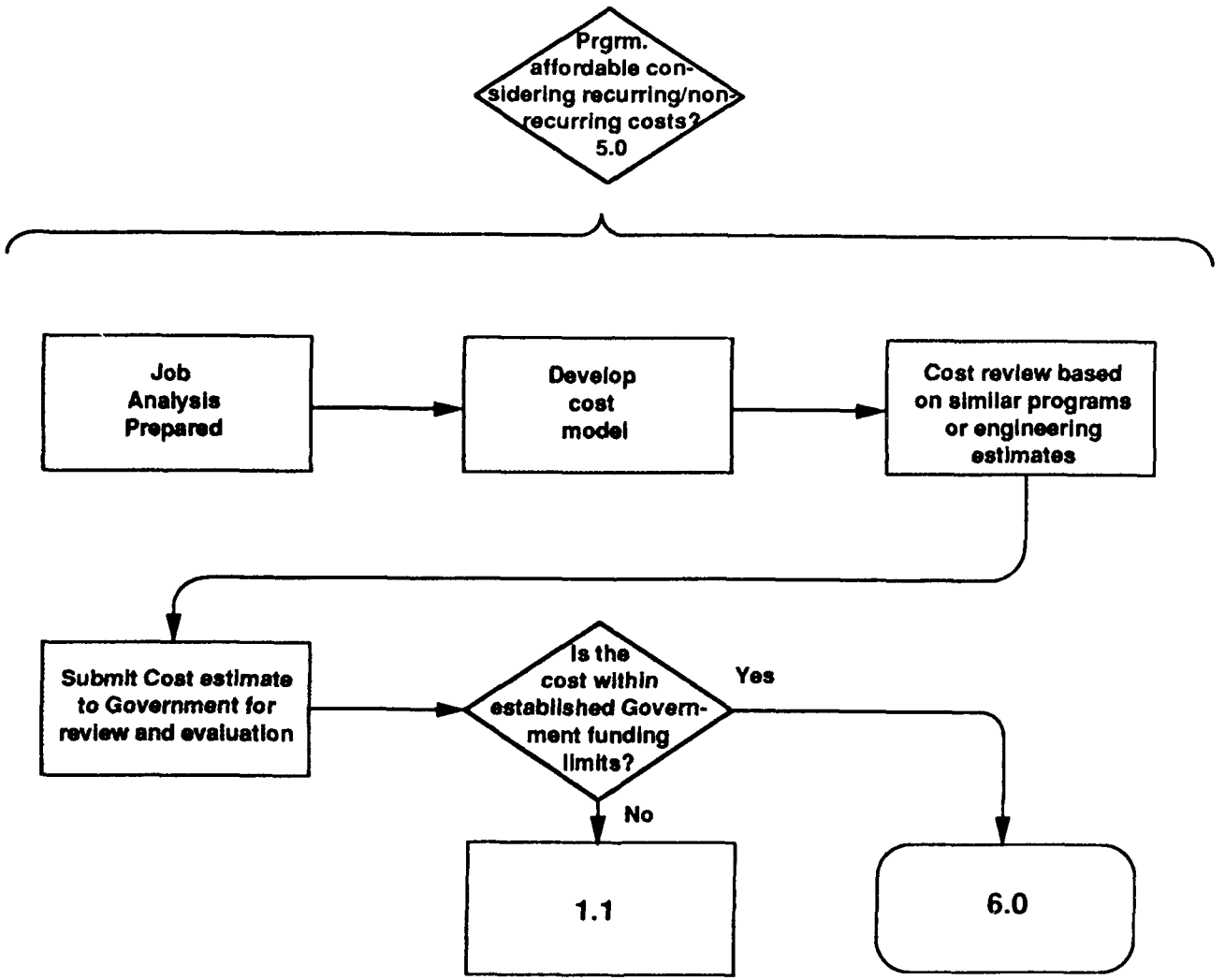

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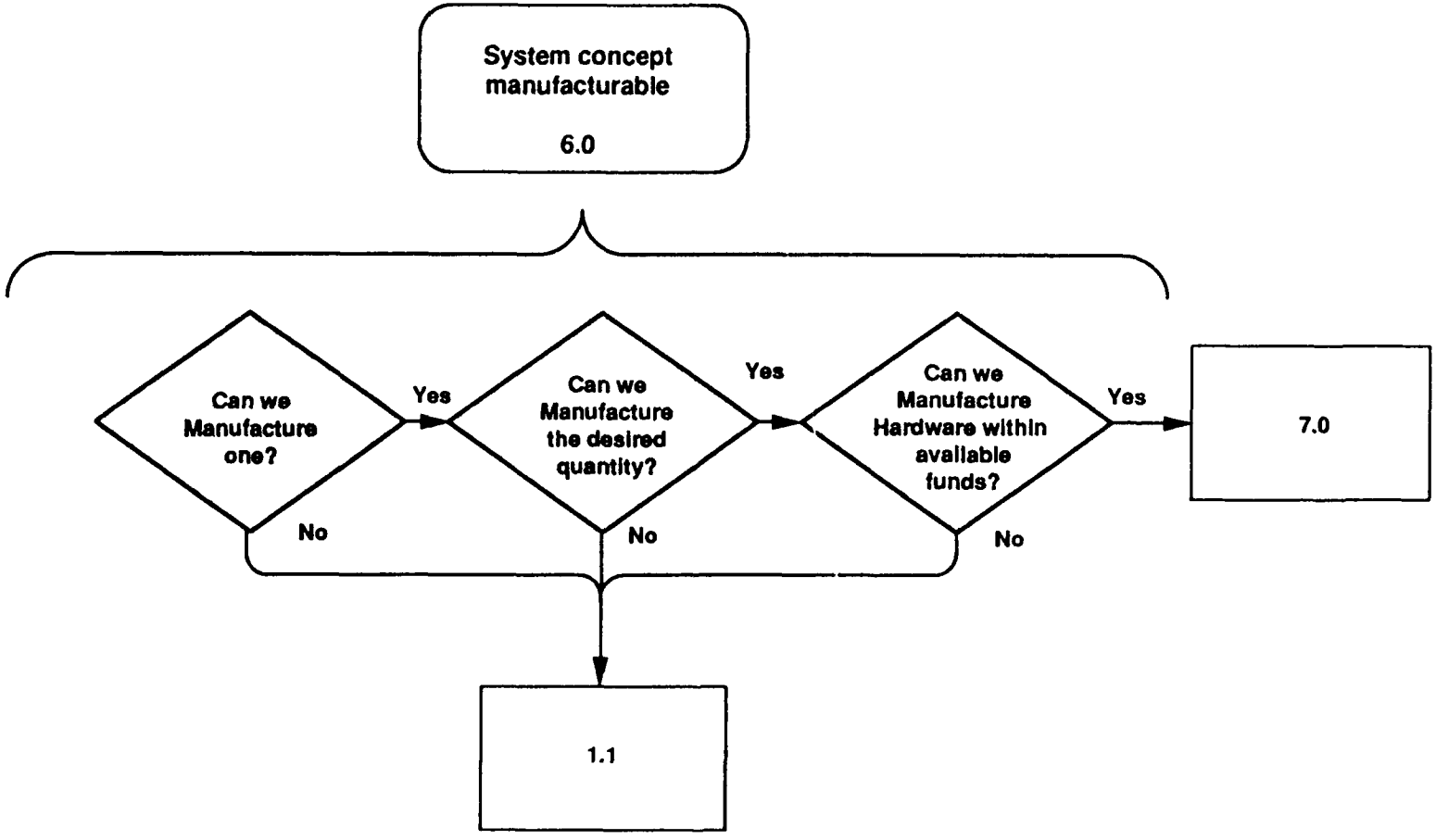


4.4 AT THE SYSTEM DESIGN REVIEW (SDR)

At SDR, the contractor and the government must know if the concept is feasible to manufacture. A rough estimate of cost and schedule to manufacture the present conceptual design should be established, and as the design becomes better defined, the cost and schedule estimate will be updated. The contractor will have compared capability and capacity requirements with availability to know if development of new processes are required or possible. He will also have identified funding requirements for new capabilities and capacities and will have risk identified, along with rough baseline design/manufacturing concept.

A review of production capability will be accomplished, which will constitute an assessment of the facilities, materials, methods, processes, equipment, and skills necessary to perform Full Scale Development (FSD) and Production. Identification of requirements to upgrade or develop manufacturing capabilities should be made, and requirements for Manufacturing Technology (MANTECH) and Industrial Modernization Incentives Programs (IMIP) should also be identified as an element of the production assessment.

Management controls and the design/manufacturing engineering approach should be presented to assure that the equipment is producible. MIL-STD-1521B requires the following manufacturing and producibility issues to be addressed at the SDR:

1. Production capability assessment (requirements vs needs)
2. Engineering design/cost of the system
3. Manufacturing requirements affecting unit production cost (UPC)
4. UPC baseline estimate
5. Risks identified, ranked, avoided, and reduced
6. Changes to current manufacturing processes or new technologies required
7. Projected capital investment needs
8. "Hardware Proofing" and high risk long-lead items
9. Manufacturing methods/process selection
10. Life cycle cost/design-to-cost goals
11. Training and training support
12. Automated versus manual operation
13. Design versus manufacturing consideration

4.5 THE FLOW FROM SYSTEM DESIGN REVIEW TO CRITICAL DESIGN REVIEW (CDR)

(Refer also to the top level fold-out flow chart on the last page.)

Block 7.0 "Designer constantly interfacing with engineering disciplines translates system requirements into design specifications and specifications into drawings" requires the design engineer to work closely and continuously throughout development with all functional disciplines in the design team to generate a producible design. This occurs simultaneously with **Block 8.0 "Manufacturing engineers working with design engineers translate specifications and drawings into manufacturing requirements."** The design team determines material needs and reviews engineering properties to select potential material and component candidates. The manufacturing engineers then identify manufacturing processes compatible with the materials and components selected (see detail page 18). When this is done, the contractor can go on to optimize his cost and schedule (Blocks 9.0 and 10.0)

Block 9.0 "Perform/update Pareto and critical path analysis to select high cost and long cycle candidates for cost and schedule optimization analyses" tells us to use the Pareto principle to determine which areas of study will give the best payback. This principle says that eighty per cent of the cost or problems occur with twenty per cent of the candidates. We should also use critical path analysis to see which tasks are likely to cause schedule

problems. We concentrate on the high cost and critical path candidates first (see detail page 19).

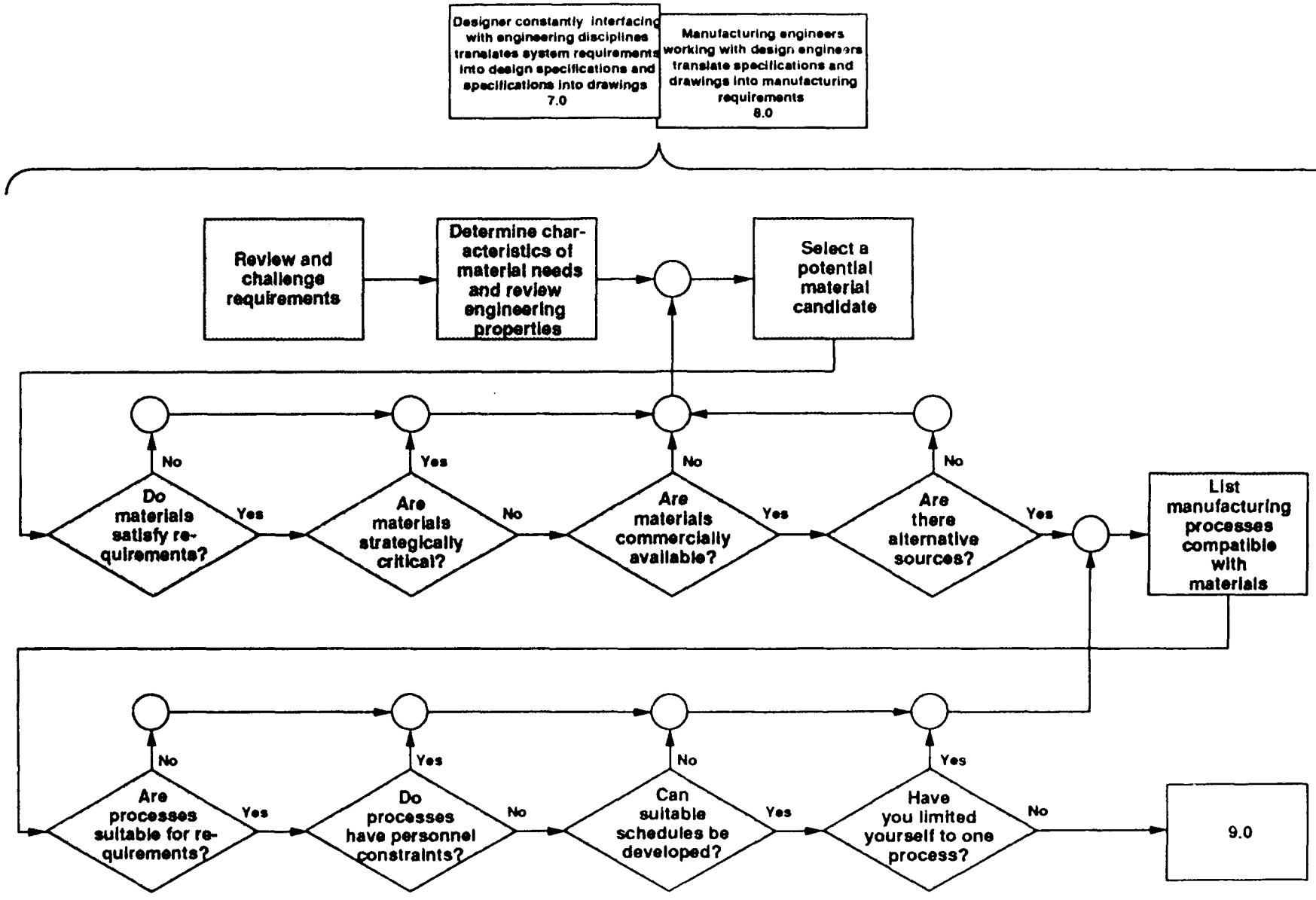
Block 10.0 "Perform/update cost/schedule optimization analyses" is where alternatives are generated, studied, and selected. The design team looks at both in-house and supplier alternatives to designs, materials and processes for cost and schedule drivers. They define manufacturing requirements, establish cost and schedule estimates, and compare performance technical advantages, cost, schedule, quality, etc., for each alternative (see detail page 20). Based on the results of the study, the team selects *the design and process combination* that optimizes cost, schedule, and performance.

Block 11.0 "Have requirements for fabrication and assembly changed?" If there has been a change to functional requirements, design, or manufacturing processes, the contractor must document the changes and return to the proper place in the flow to continue the iterative design process. If there is a design or a manufacturing process change, he must return to Block 7.0 or 8.0. If there is a requirements change, he must return to Block 2.0 and reestablish whether he has the capability and capacity to manufacture the design with revised requirements (see detail page 21). From Block 2.0, he should go through the complete producibility flow, at least as a check, until he comes back to Block 11.0.

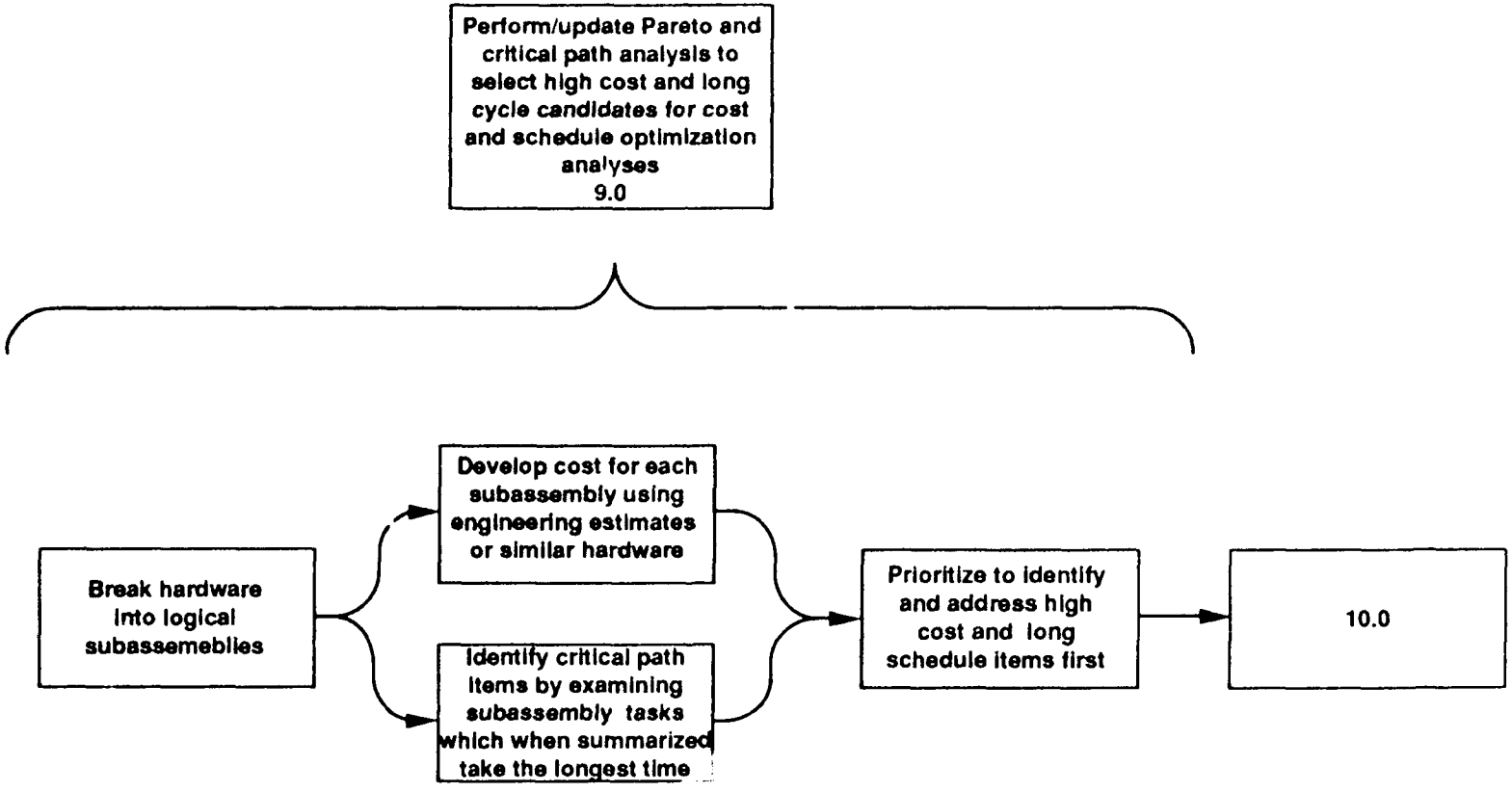
Block 12.0 "Is additional analysis cost effective?" As schedule problems are resolved on the longest critical path items and costs are reduced on the top cost drivers, the contractor focuses on the next highest cost and schedule drivers until the top twenty per cent of the problems are resolved. At this point, both the contractor and the customer need to look at the expected returns from further Pareto analyses and optimization studies to see if it is cost effective to return to Block 9.0, or whether diminishing returns dictate that they should move on (see detail page 22).

Block 13.0 "Are all drawings complete?" is a "sanity check" to be sure all responsible engineering disciplines have approved and have taken responsibility for all manufacturing drawings. If not, we must return to Block 7.0 to complete the process. It is obviously impractical to delay production planning until all drawings are complete on every item of a system. Schedules will demand that production planning be done for some items even while the designs for others are incomplete. Since design for producibility is an *iterative process*, we will be *simultaneously at many places in the flow with different items of hardware*, but our drawings should be complete for those items we are planning to produce.

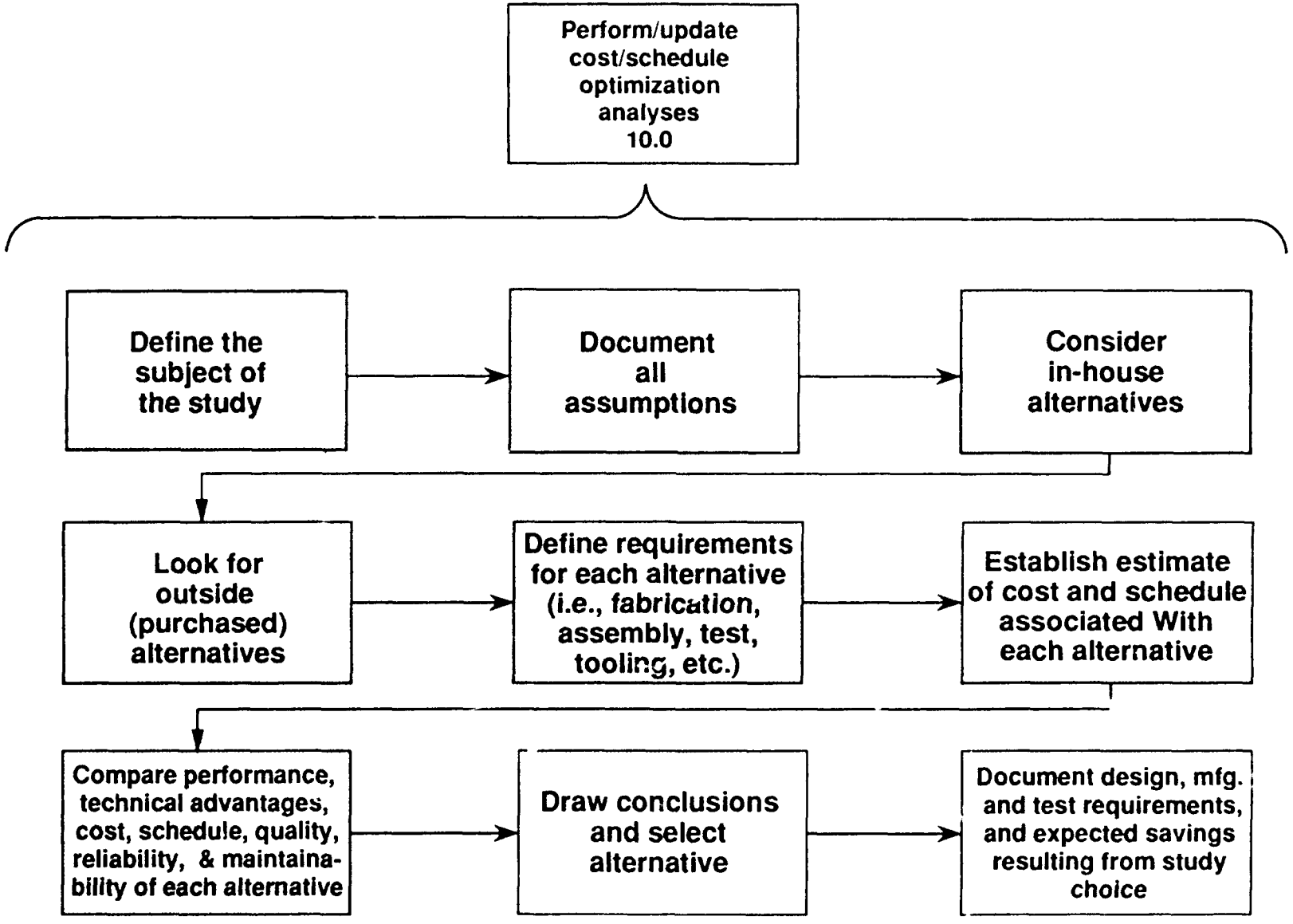
Design/Development Flow: 7.0/8.0



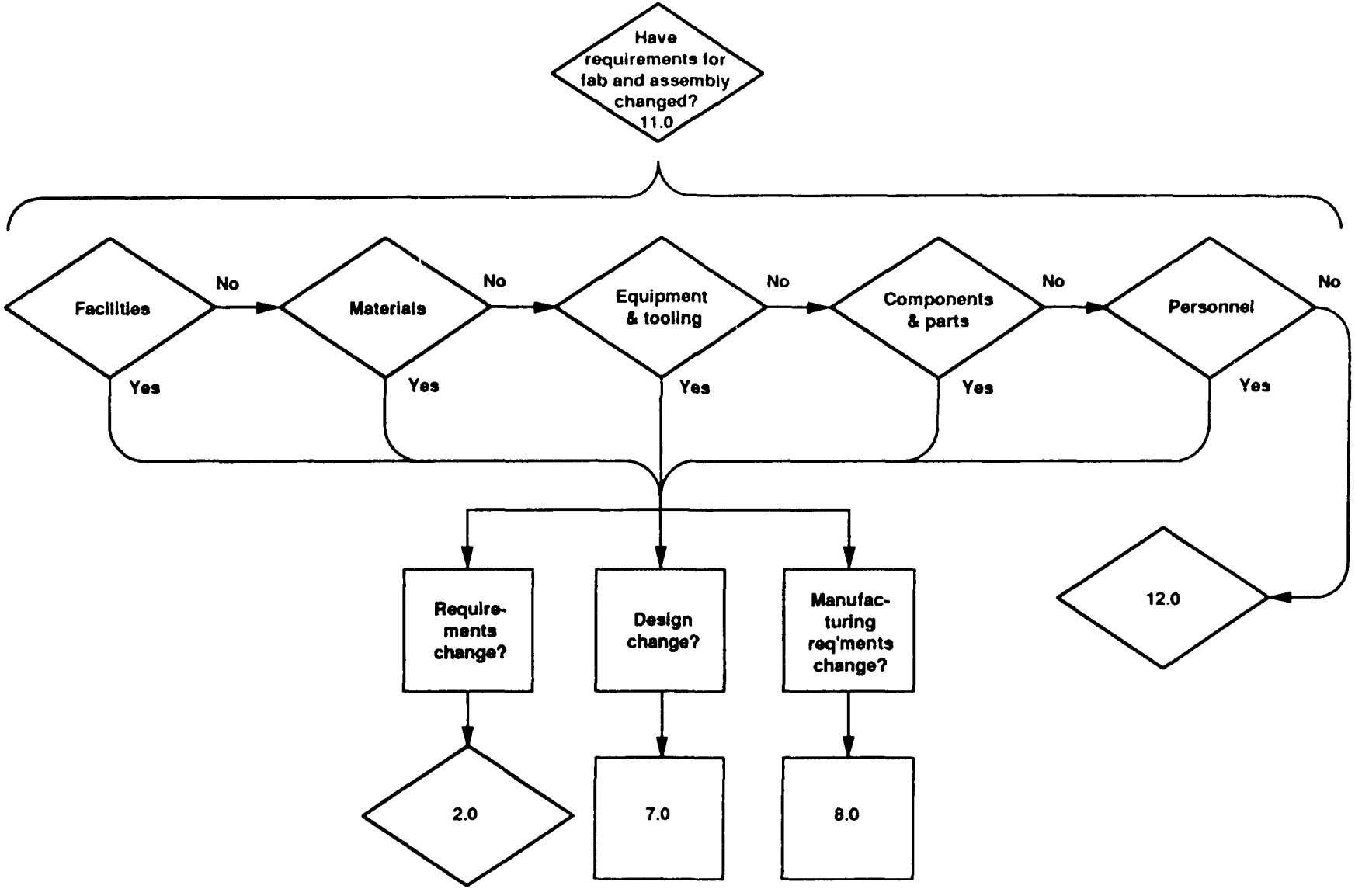
Design/Development Flow: 9.0



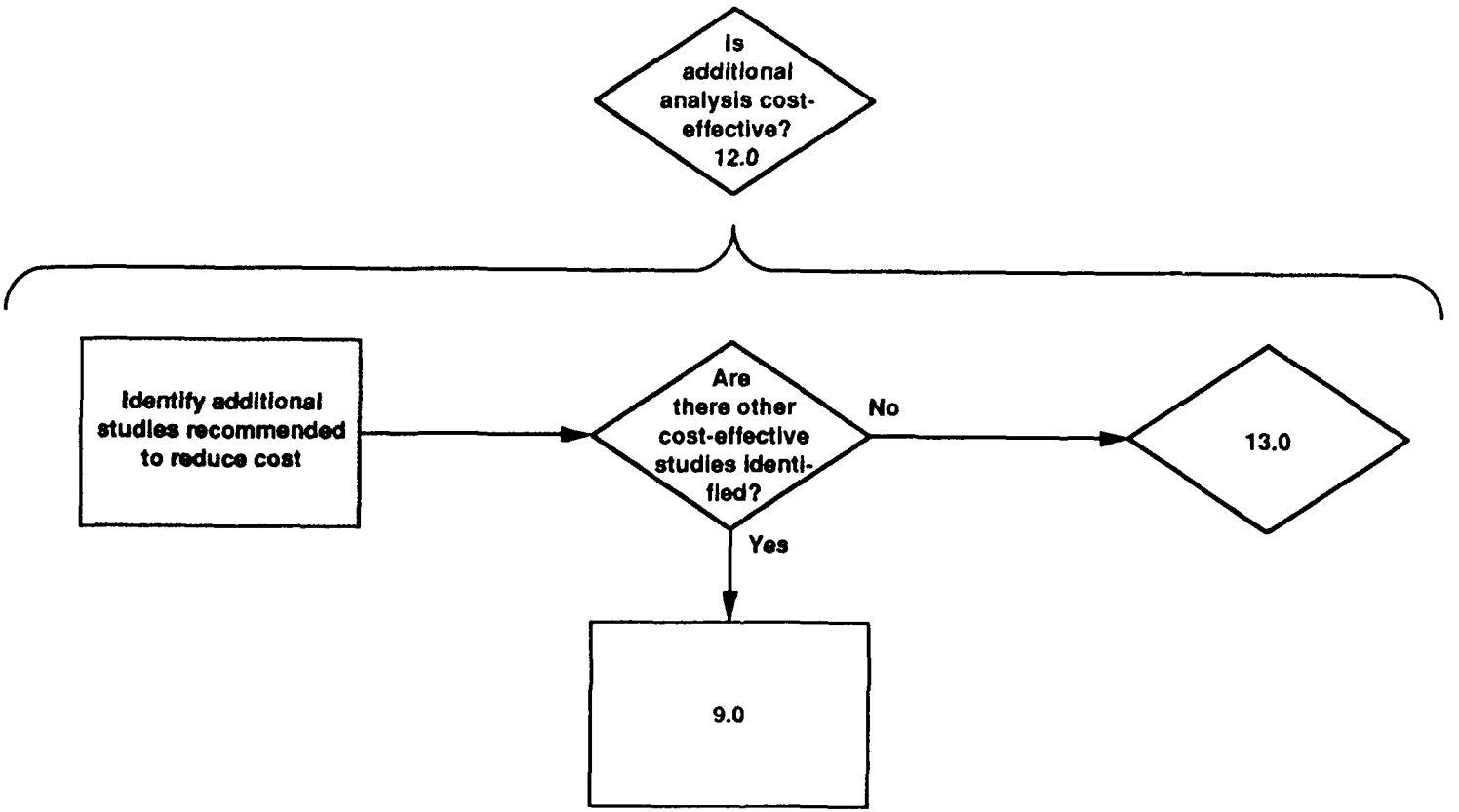
Design/Development Flow: 10.0



Design/Development Flow: 11.0



Design/Development Flow: 12.0



4.6 AT THE PRELIMINARY DESIGN REVIEW (PDR)

The PDR is a formal technical review of the basic design approach for a configuration item or for a functionally related group of configuration items. The overall technical program risks associated with each configuration item are also reviewed on a technical, cost, and schedule basis. The contractor provides evidence of performing producibility analyses on development hardware trading off design requirements against manufacturing risk, cost, production, volume, and existing capability/availability. Preliminary manufacturing engineering and production planning demonstrations at this stage should address: material and component selection, preliminary production sequencing, manufacturing methods and flow concepts, new processes, manufacturing risk, equipment and facility utilization for intended rates and volumes, production-in-process, and acceptance test/inspection concepts.

The producibility and manufacturing concerns identified in the SRR and the SDR will be updated and expanded to provide evidence that concerns identified in the manufacturing feasibility assessment and the production capability estimate have been addressed and that resolutions are planned or have been performed. MIL-STD-1521B requires the following manufacturing and producibility issues to be addressed at the PDR:

1. Tracking of average unit production cost versus SDR baseline UPC estimate
2. Review of trade studies for design requirements against requirements for producibility
3. Preliminary manufacturing engineering and production planning demonstrations
4. Review of concerns identified in the production capability assessments
5. Identification of recommendations for industrial modernization
6. Review of contractor planning for transition to production
7. Trade study and design studies results
8. Preliminary lists of materials, parts, and processes
9. Producibility and manufacturing considerations (e.g., materials, tooling, test equipment, processes, facilities, skills and inspection techniques). Identify single, sole, and diminishing sources.
10. Life cycle cost analysis

4.7 BETWEEN PRELIMINARY AND CRITICAL DESIGN REVIEWS

Between the PDR and CDR the design and manufacturing processes are solidified and specified in greater detail through the iterative design and manufacturing planning process. If we compare the products of the two reviews, we see this difference. At PDR, the contractor will:

1. Have documented the current design baseline
2. Know if the present design baseline is manufacturable
3. Have performance requirements translated into specifications
4. Have specification requirements translated into manufacturing requirements
5. Know if fabrication/assembly and cost/schedule of current design
6. Have performed and documented cost (Pareto) analysis and critical path
7. Have performed and documented cost/schedule optimization analyses
8. Have identified future cost/schedule optimization analyses.

At CDR, by comparison, the contractor will:

1. Have detailed design documented
2. Have manufacturing capability/capacity planned and documented, including:
   (a) Allocating existing capability/capacity
   (b) Planning new capability/capacity
   (c) Programming long lead and/or program critical items

3. Have cost/schedule optimization analyses completed and implemented for at least the costliest 20% of the hardware items
4. Have funded and satisfactorily scheduled all new capability/capacity requirements
5. Have risk mitigation plan in effect

4.8 AT THE CRITICAL DESIGN REVIEW (CDR)

At CDR, the overall technical program risks associated with each configuration item are reviewed on a technical (design and manufacturing), cost and schedule basis. The result of a successful CDR is the establishment of the design baseline for detailed fabrication/production planning; i.e., the contractor should be permitted to use the detail design as presented at CDR and reflected in the hardware product specification for planning for production and, if specifically authorized, for initial fabrication/production efforts. Adequacy of the detailed design should be addressed for many functional areas, not the least of which are producibility and manufacturing.

MIL-STD-1528A requires a review of initial manufacturing readiness; e.g., manufacturing engineering, tooling demonstrations, development and proofing of new materials, processes, methods, tooling, test equipment, procedures and reduction of manufacturing risks to acceptable levels. It also calls for mock-ups, breadboards, and/or prototype hardware. MIL-STD-1521B requires the following manufacturing and producibility issues to be addressed at CDR:

1. Review the status of all producibility (and productivity) efforts for cost and schedule considerations.
2. Review the status of efforts to resolve manufacturing concerns identified in previous technical reviews and their cost and schedule impact to the production program.
3. Review the status of manufacturing technology programs and other previously recommended actions to reduce cost, mitigate risk and minimize industrial base concerns.
4. Identify open manufacturing concerns that require additional direction/effort to minimize risk to the production program.
5. Review the status of manufacturing engineering efforts, tooling and test equipment demonstrations, proofing of new materials, processes, methods, and special tooling/test equipment.
6. Review the intended manufacturing management system and organization for the production program in order to show how their efforts will effect a smooth transition into production.

4.9 THE FLOW BEYOND CDR

(Refer also to the top level fold-out low chart on the last page.)

Block 14.0 "Are all production requirements planned and documented?" To make final plans for Production requires that there be a stable design, that all resources are planned and documented, that processes and tooling are identified, that materials and/or purchased parts are selected and/or issued, that manufacturing methods are established and documented, and that quality control is in place. If any of these items are missing, risk areas must be identified and corrective action acceptable before proceeding (see detail page 26).

Block 14.1 "Identify risk areas, corrective actions and document" forces us to determine if the risk to manufacturing integrity is acceptable. If it is not, we must define the requirements to reduce the risk to an acceptable level. If the risk cannot be reduced to an acceptable level, the contractor and the customer must decide whether they can afford to proceed with a known high risk. (see detail page 27).

Block 14.2 "Go ahead with risk identified and corrective action in place?" is where the decision must be made, if risk is inevitable, to go ahead or to stop the program. If the risk is unacceptable, the program will be halted. If the risk is too high, and the program cannot be halted, a decision must be made to change the functional requirements, the design, or the manufacturing processes to mitigate or eliminate the risk. At this point, we must reenter the design flow at the appropriate place, repeating all the steps until we again reach Block 14.0 (see detail page 28). If the risk or corrective actions are judged acceptable at the first or subsequent iterations, the decision is made to proceed with the program (Block 15.0).

Block 15.0 "Production risk is acceptable. Proceed with program." The Production decision (Milestone IIIA) is the milestone indicating that both the contractor and the customer have done all required analyses in sufficient depth and have determined that the risks, whether technical, cost or schedule, are not sufficient to prevent the program from going to production.

Block 16.0 "Maintain surveillance of contract pursuant to the requirements of MIL-STDs-1528A and 1567A" is not part of the design flow; however, the customer must monitor the contractor's performance against cost and schedule to determine whether manufacturing performance is acceptable (see detail page 29). This is important for feedback and to document lessons learned.

5.0 PRODUCIBILITY SUCCESS MEASUREMENT

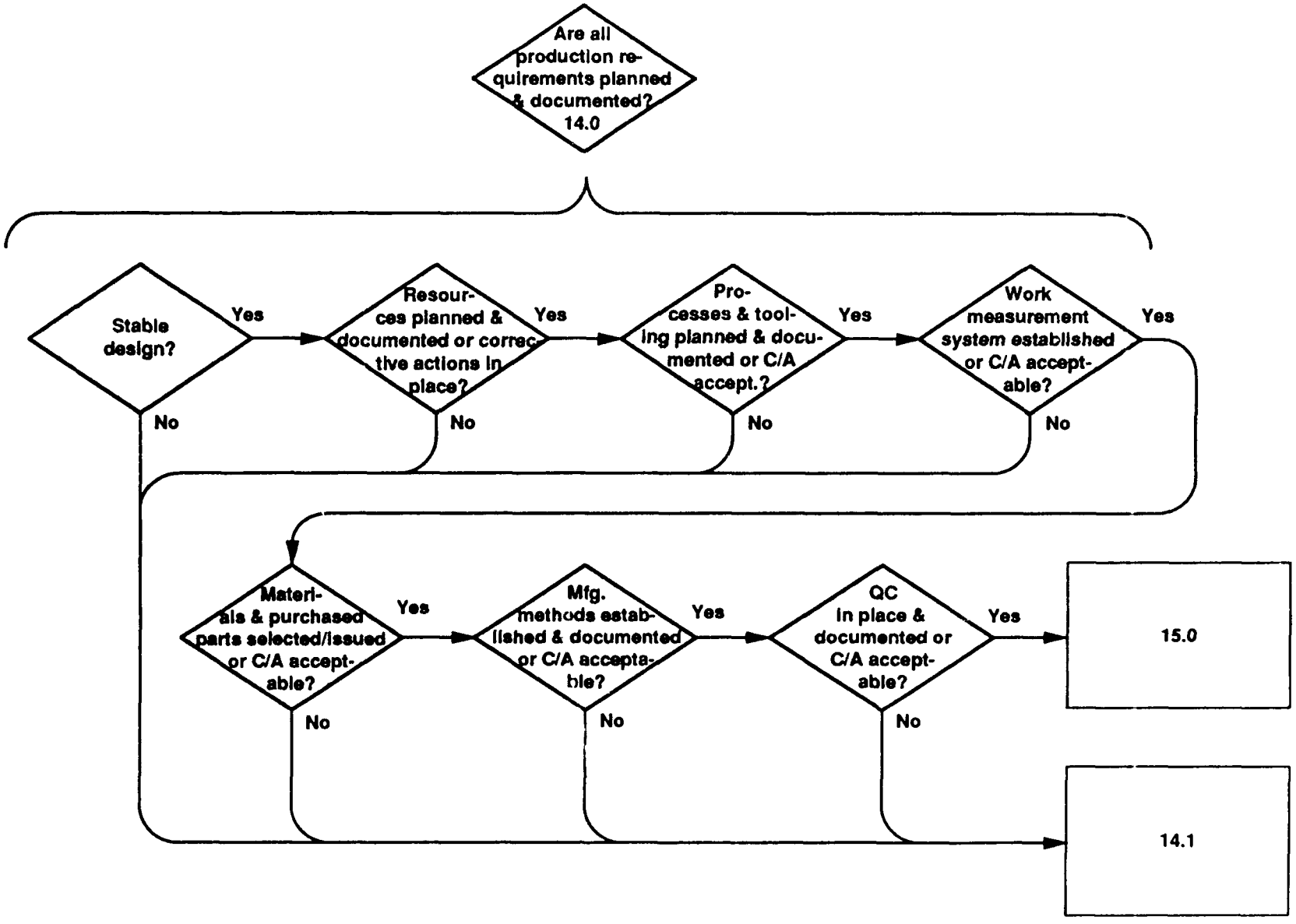
Ultimately, successful development and production programs are implemented without fanfare. This happens because perfection is the expectation of an engineering and manufacturing organization. This makes it difficult to measure success. The easiest method of measuring producibility success is to measure the lack of perfection through such things as the number of required engineering changes. The best possible method of measuring producibility success is to track the accomplishment of meaningful goals set at the beginning of a project. These goals can take the form of unit production cost, use of certain materials or processes, elimination of materials or processes, number of hours to build and/or test major subassemblies, etc.

6.0 CONCLUSION

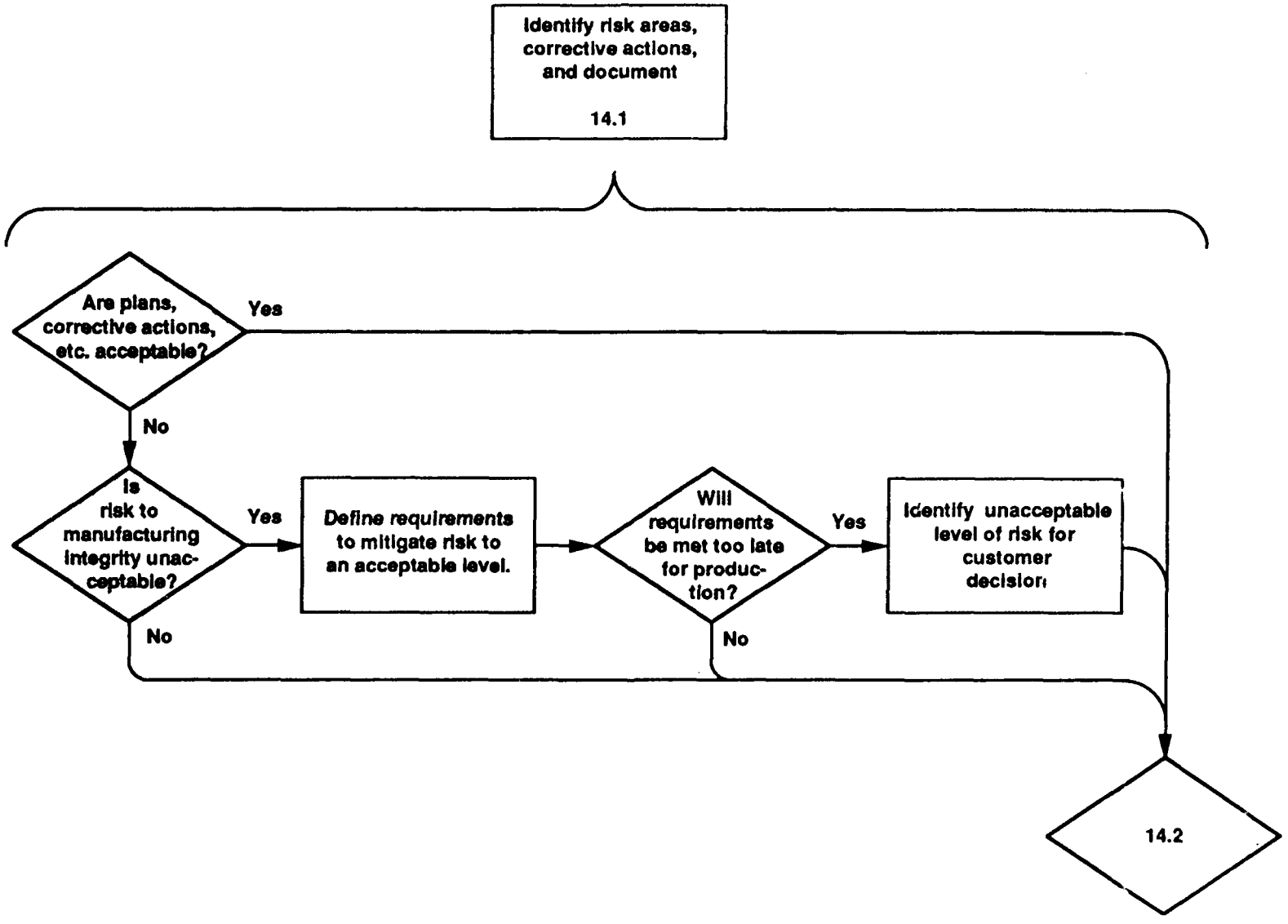
The tasks outlined above are neither unique nor esoteric. They are common to every successful acquisition program. Sometimes they are done unconsciously, with the result that lessons learned are seldom passed on. Sometimes the tasks are done only in part, with the result that success, if achieved at all, is also only in part. If you follow this algorithm in its entirety, you will take all the steps you need to achieve a producible product.

Our program success in production is directly tied to the producibility of our product. This algorithm is a positive step to inform people and improve our process, but it is only a first step. It will require follow-up and corrective action to achieve complete success. As we've all seen from experience, it is not our failure to *know* that keeps us from achieving our goals in most cases, but our failure to *do* what we've known all along that we should do.

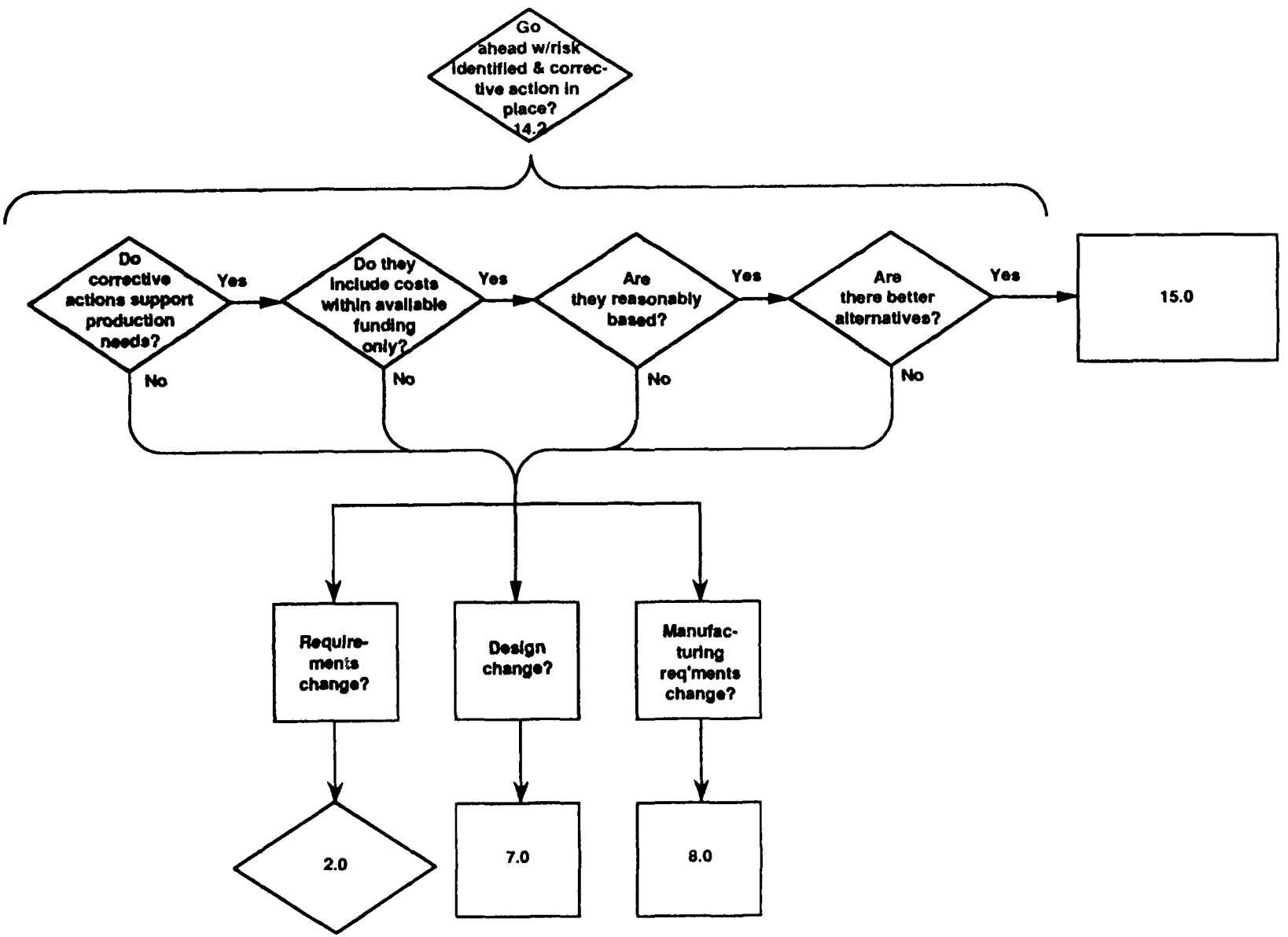
Manufacturing Execution: 14.0



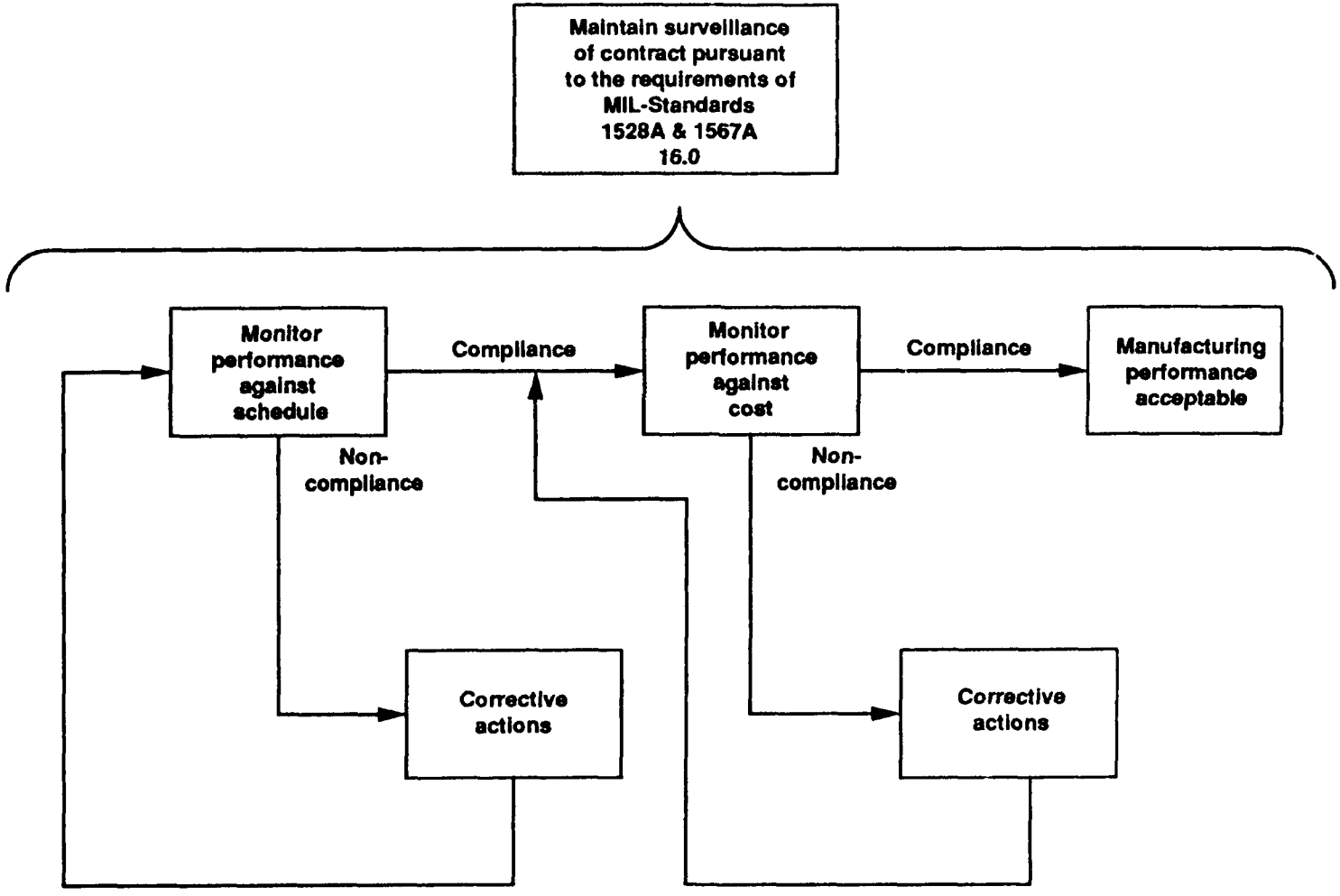
Manufacturing Execution: 14.1



Manufacturing Execution: 14.2



Manufacturing Execution: 16.0



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